

# Competitive Academic Agreement Program



## Advancement in the Area of Intrinsically Locatable Plastic Materials

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# Project Team

- **Project PI/co-PI:** Udaya B. Halabe,  
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- **Graduate Students:** Jonas Kavi, Ben Imes,  
and Andrew Cvetnick



# Background

- US has 2.7 millions miles natural gas and hazardous liquid transmission and distribution pipeline
  - 2.5 million miles of natural gas
  - 0.2 million miles of hazardous liquid



# Background (cont.)

Major challenges of the pipeline industry:

- Corrosion of steel pipes.
- Excavation damage.
- Material failure.
- Above factors ~ 66% of pipeline failures.



Pipeline incidents in TX and CA  
(Source: DOT, NTSB, Sacramento Bee)



# Main Objective

Develop strategies for creating and locating buried non-metallic pipe materials through the following research activities:

- Develop, investigate, and compare alternative strategies for creating easily locatable Fiber Reinforced Polymer (FRP) pipes.
- Carbon and Glass Fiber Reinforced Polymers – CFRP and GFRP.
- Aluminum or CFRP fabric overlay for GFRP and PVC pipes.
- Investigate pipe detectability using Ground Penetrating Radar (GPR) and Infrared Thermography (IRT).
- Investigate the feasibility of gas leak detection.



# Industry Needs

- Natural Gas Transmission lines- 20” to 40” Dia.  
200 to 1500 psi
- Increase in demand - higher pressures needed (3000-5000 psi)
- Increase in service life - corrosion, hydrogen embrittlement, nano cracking.
- Increase in safety - 100 deaths each year
- Increase detectability



# Proposed Material

- Glass Fiber Reinforced Polymer (GFRP) offers
  - Corrosion resistance-soil interaction, pH, Moisture
  - Resistance to hydrogen embrittlement
  - Less electrical conductivity than steel
  - Less thermal conductivity - fire resistance
  - Higher strength to weight ratio than steel
  - Superior flexibility - differential settlement
  - Potential for easier detectability



# Pultruded 16" Dia GFRP Pipe

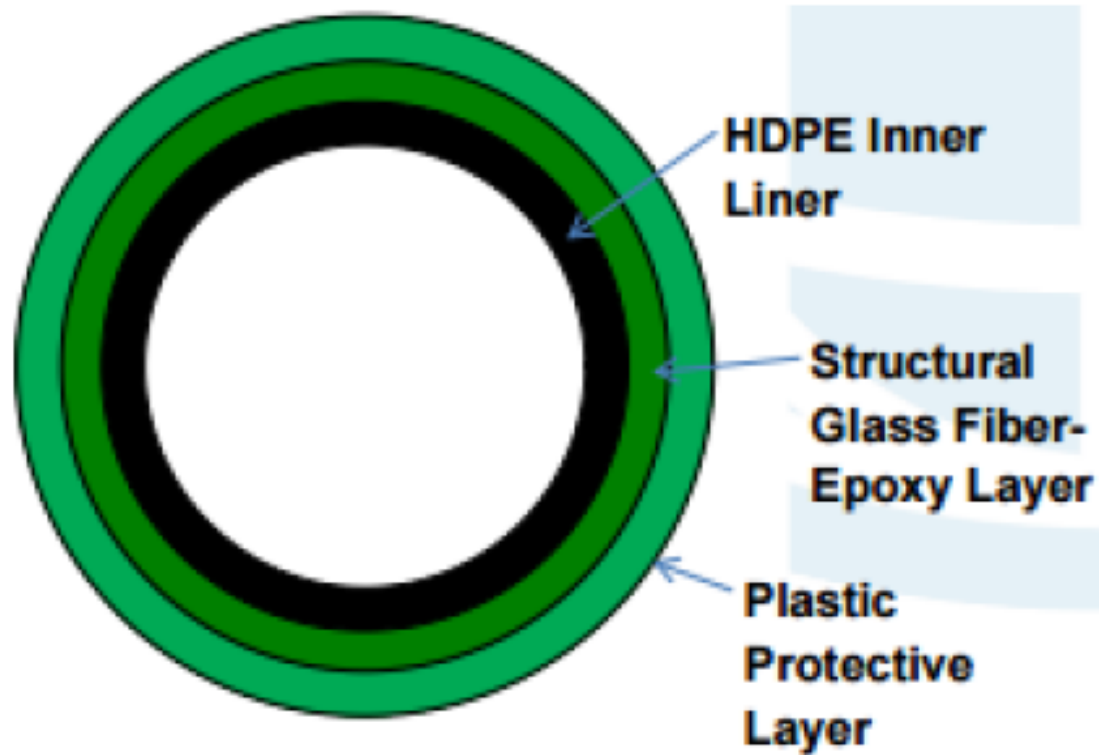


# Pipe Burst Test

- Design of GFRP pipe (6"- 10") ~ 2500 psi burst pressure
- Static and Fatigue load testing
- Another CAP research project is currently underway to increase burst pressures up to 10,000 psi



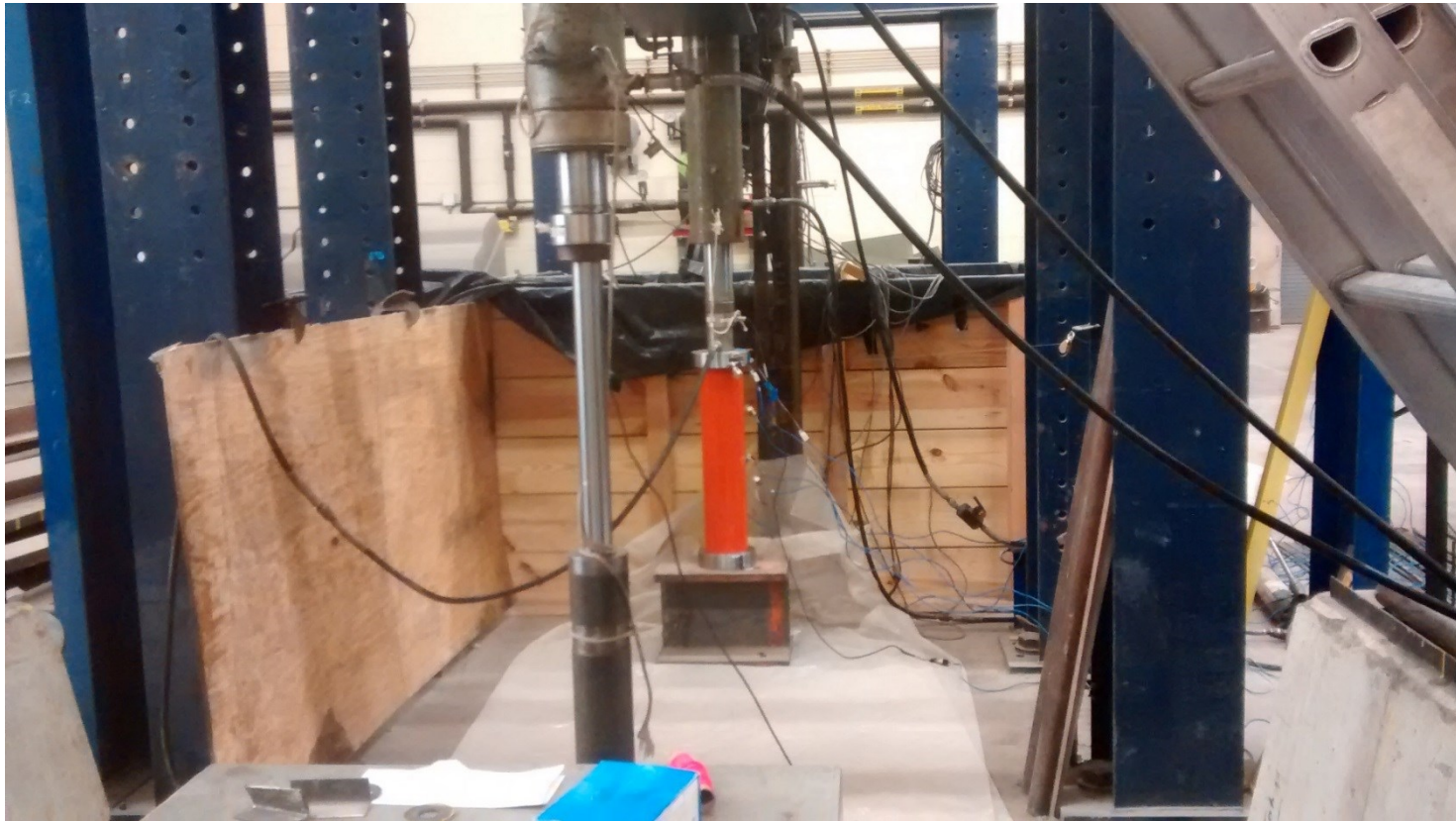
# GFRP Pipe Cross Section



# End Caps



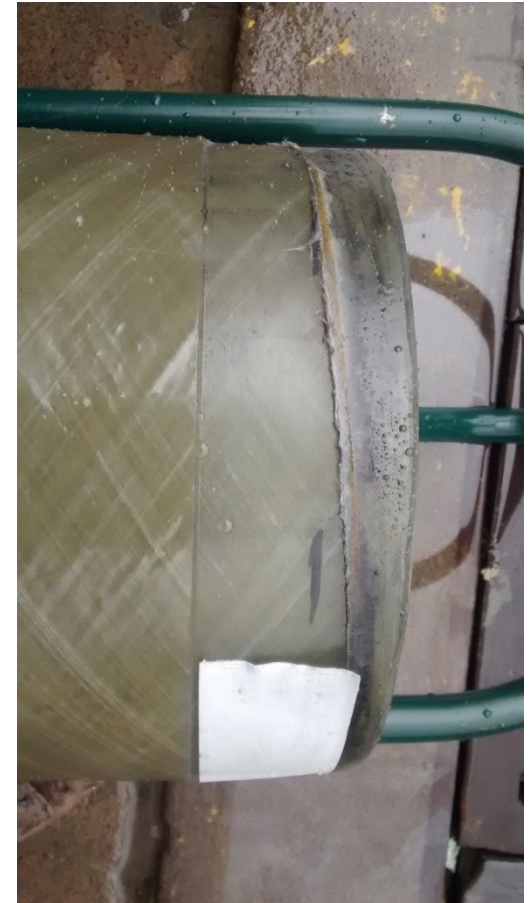
# 6 Inch Diameter Pipe



# 10 Inch Pultruded Pile



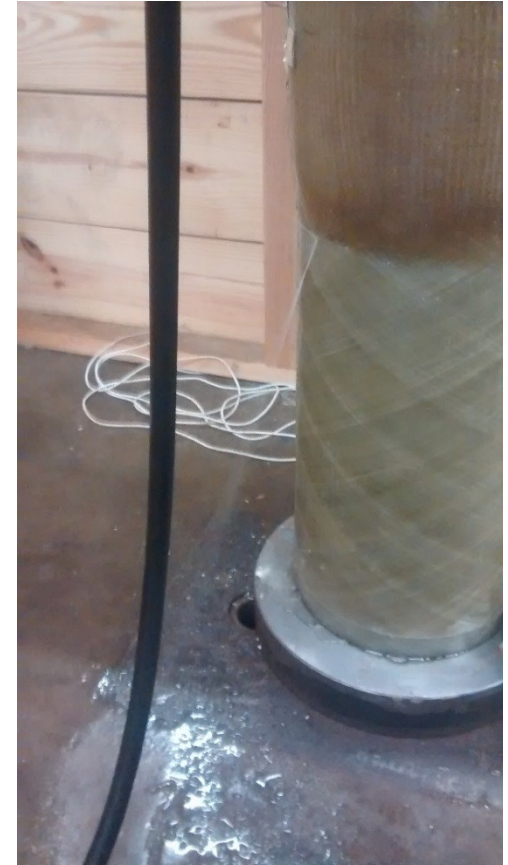
# 10 Inch Filament Wound Pipe



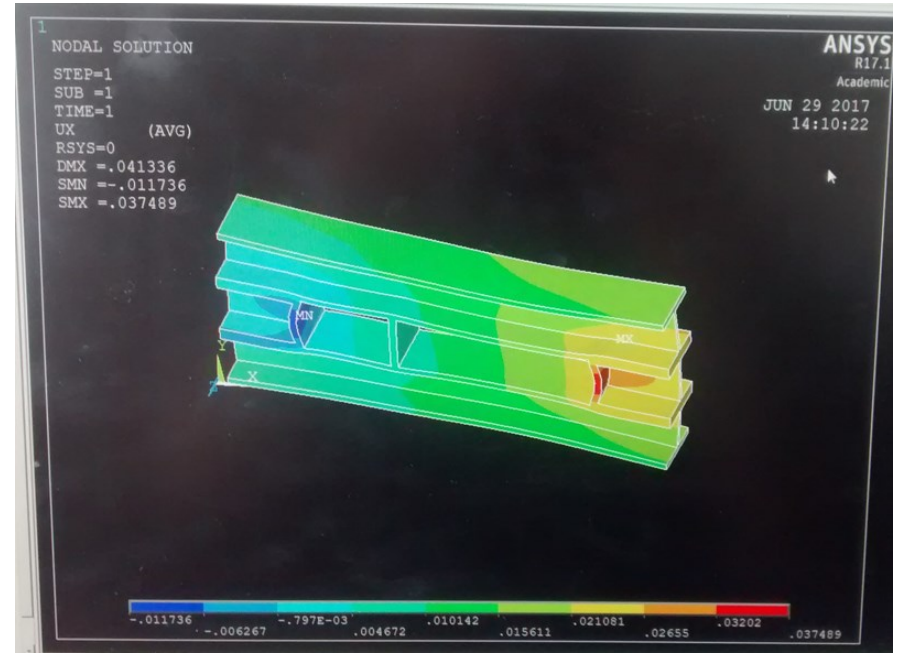
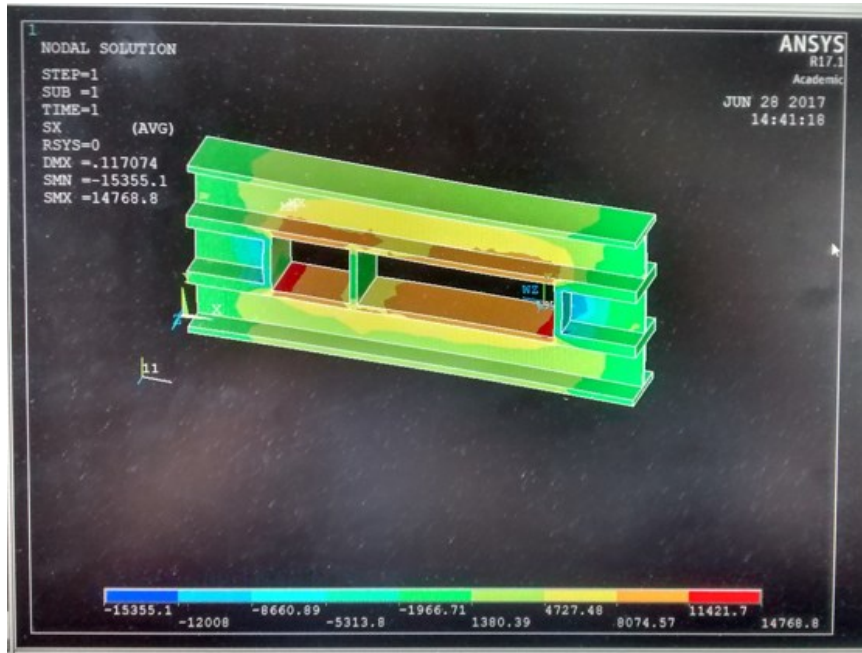
# Frame Setup Revision Two



# 10 Inch Diameter Pressure Test



# Test Frame Design



## A schematic diagram of a multi-layered structure. The central part consists of a yellow rectangular block on the left, followed by a small yellow gap, then a green rectangular block with a cross-hatch pattern, and finally another small yellow gap. This central assembly is flanked by two blue vertical bars. The entire structure is enclosed within a white rectangular frame. The top and bottom edges of the frame are marked with a series of red vertical bars. The left and right edges of the frame are marked with a series of red vertical bars. The top and bottom edges of the frame are also marked with a series of red vertical bars. The left and right edges of the frame are also marked with a series of red vertical bars.

# Test Frame



# GPR and IRT for Buried Pipe Detection



**GPR equipment setup**



**IRT equipment**



# Research Approach

Major tasks to achieve the objective of the project are:

- Wrap PVC and GFRP pipes with aluminum or carbon fabric strips for easy detection.
- Wrap PVC and GFRP pipes with aluminum or carbon fabric rings for easy detection.
- Investigate and compare the detectability of the above pipes (buried) using GPR.
- Investigate IRT for detecting buried pipes carrying hot liquid.



# Pipe Samples



**Sample pipes with carbon fabric  
and aluminum rings**



**Sample pipes with carbon fabric  
and aluminum strips**



# Pipe Samples (cont.)

Pipe samples were buried in 3 ditches:

- 12" diameter pipes at 4' depth.
- 12" & 6" diameter pipes at 3' depth.
- 3" diameter pipes at 2' depth.
- 11 pipes in each trench, 33 pipes in total.



**Pipe samples being buried**

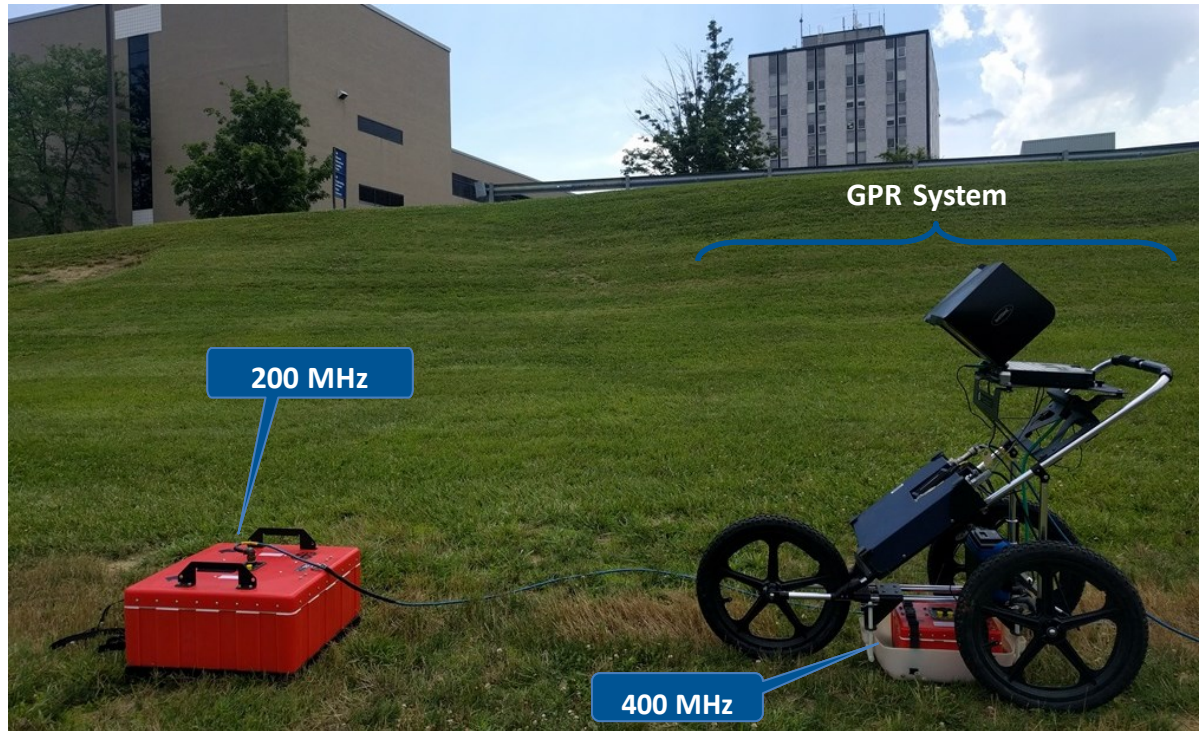


# GPR Antennae

Two different antennae evaluated



**200 MHz Antenna with  
Survey Wheel**



**GPR testing system**



# Decagon Sensors

Used for measuring dielectric constant of soil.



Soil moisture, resistivity, and dielectric constant sensor

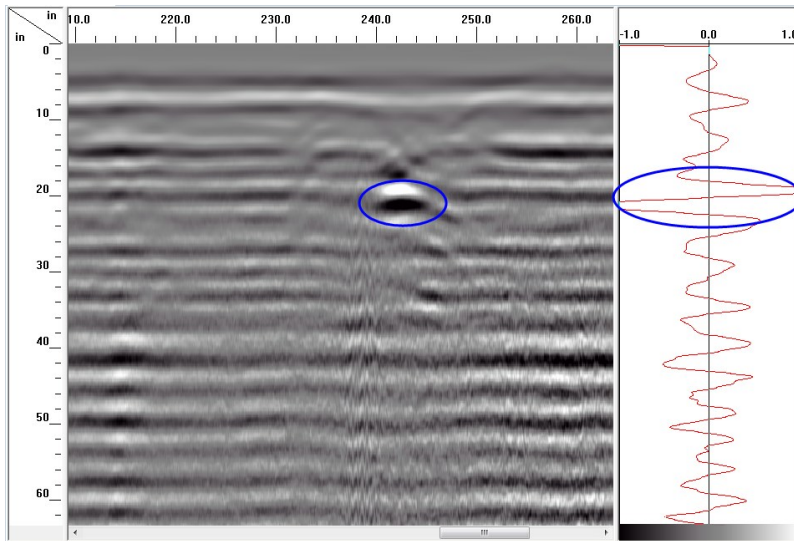


Data logger

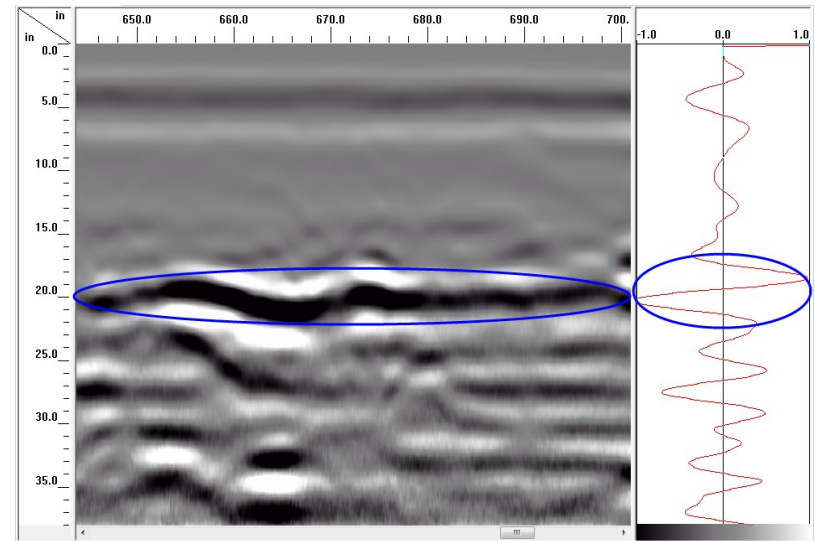


# GPR Results

3 inch diameter pipes at 2 feet depth scanned with 400 MHz antenna



**Sample cross-sectional GPR scan (left) and A-scan (right) over pipe wrapped with CFRP fabric**

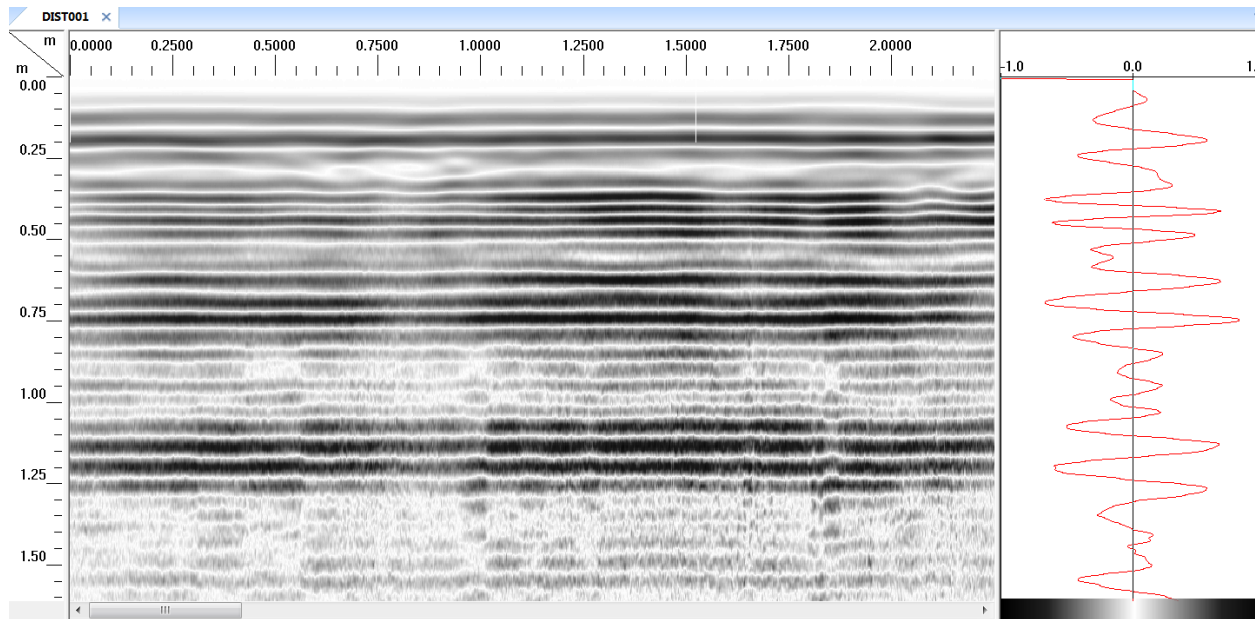


**Sample longitudinal GPR scan (left) and A-scan (right) over pipes buried at 2' depth**



# GPR Results (Cont.)

400 MHz antenna signals for pipes below 2 feet depth

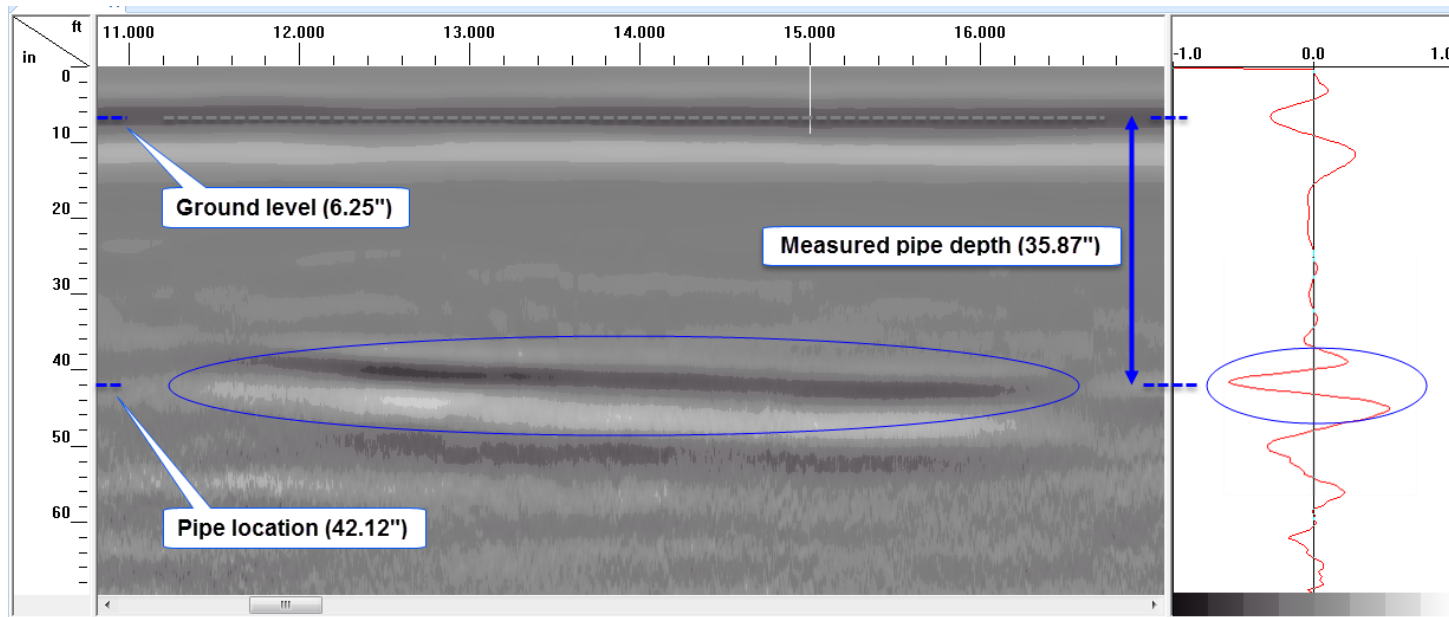


**Sample cross-sectional GPR scan (left) and A-scan (right) across three trenches**



# GPR Results (Cont.)

12 inch diameter pipes at 3 feet depth scanned with 200 MHz antenna

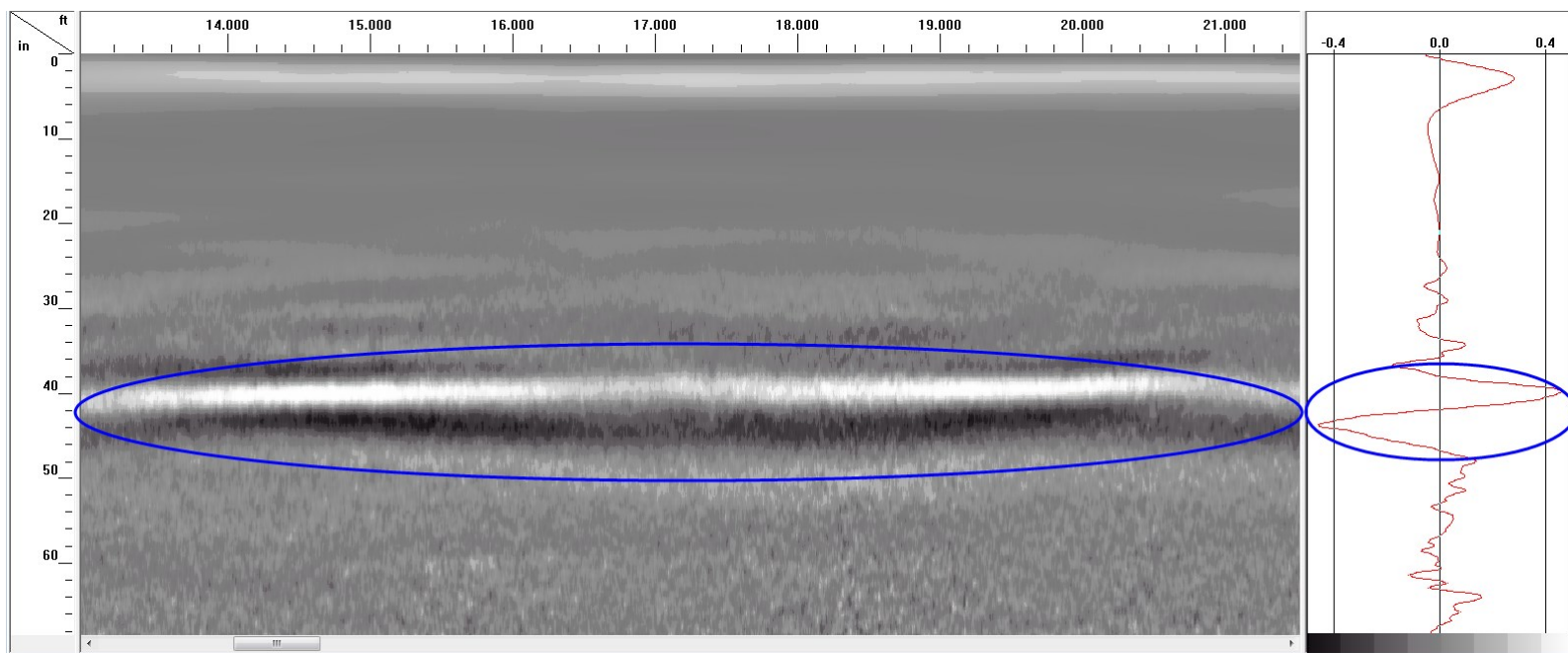


Longitudinal GPR scan (left) and A-scan (right) over GFRP pipe



# GPR Results (Cont.)

12 inch diameter pipes at 4 feet depth scanned with 200 MHz antenna

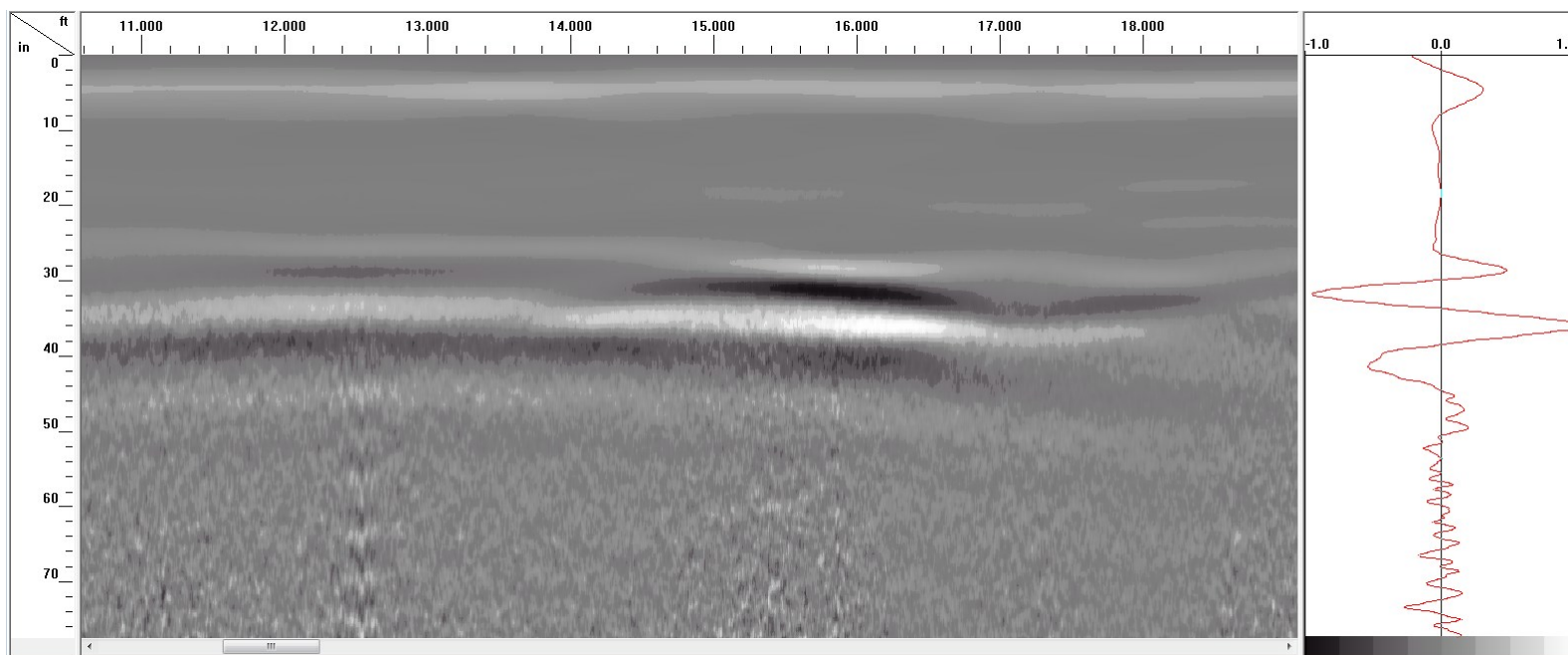


**Longitudinal GPR scan (left) and A-scan (right) over PVC pipe wrapped with CFRP fabric**



# GPR Results (Cont.)

3 inch diameter pipes at 2 feet depth scanned with 200 MHz antenna



**Longitudinal GPR scan (left) and A-scan (right) a 2 feet deep pipe**



# GPR Results (cont.)

- i. 400 MHz GPR antenna was unable to detect pipes buried deeper than 2 feet.
- ii. 200 MHz radar antenna produced significantly better result compared to 400 MHz radar antenna for buried pipe detection.
- iii. Use of CFRP fabric or Aluminum Foil on the surface made the non-metallic pipes detectable using GPR.
- iv. Precise location of the pipes using distance tracker and comparison of signals from different pipes show CFRP fabric and aluminum tape overlays significantly improve pipe detection.



# Infrared Thermography (IRT)

- A 3" diameter CFRP pipe buried in a wooden box.
- A mixture of gravel, sand and top soil medium.
- 14" soil cover.

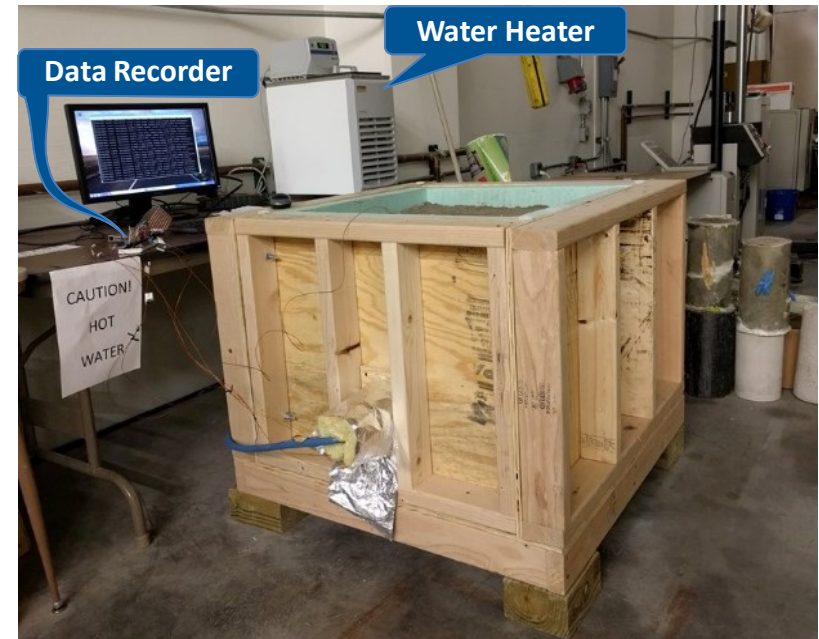


Pipe samples being buried



# IRT Test Setup

- 5 thermocouples on pipe surface.
- 1 thermocouple at soil surface.
- Hot water (95°C) pumped through pipe.
- IRT and thermocouple data collect periodically.

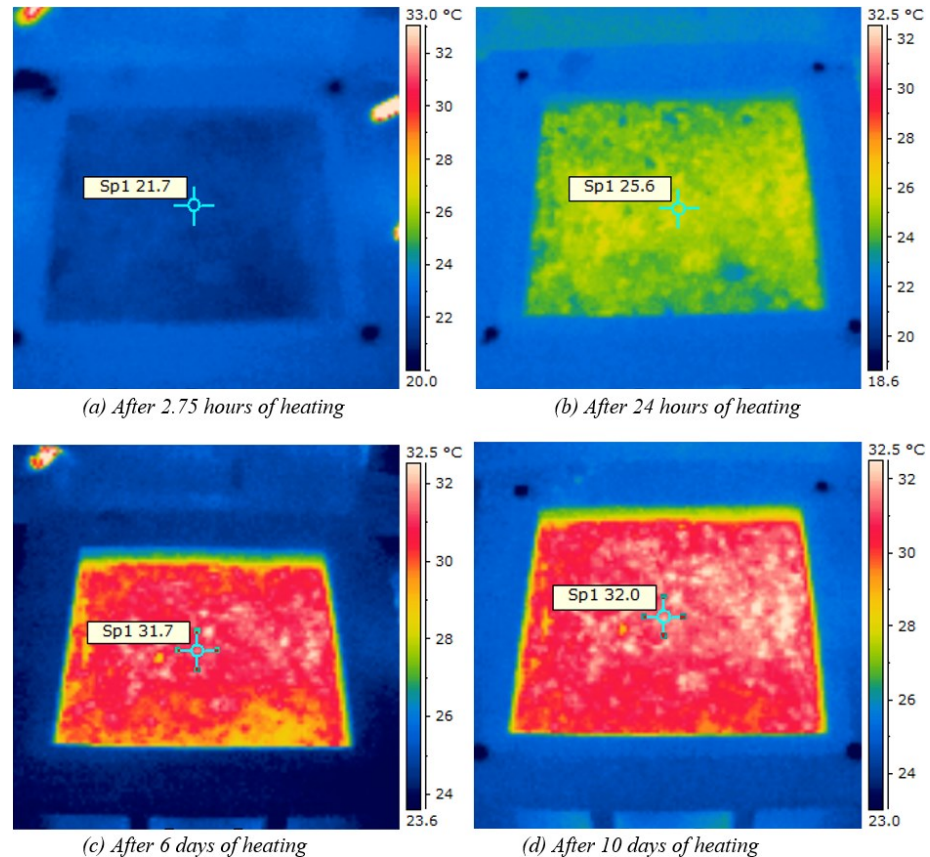


IRT Test Setup



# IRT Test Results

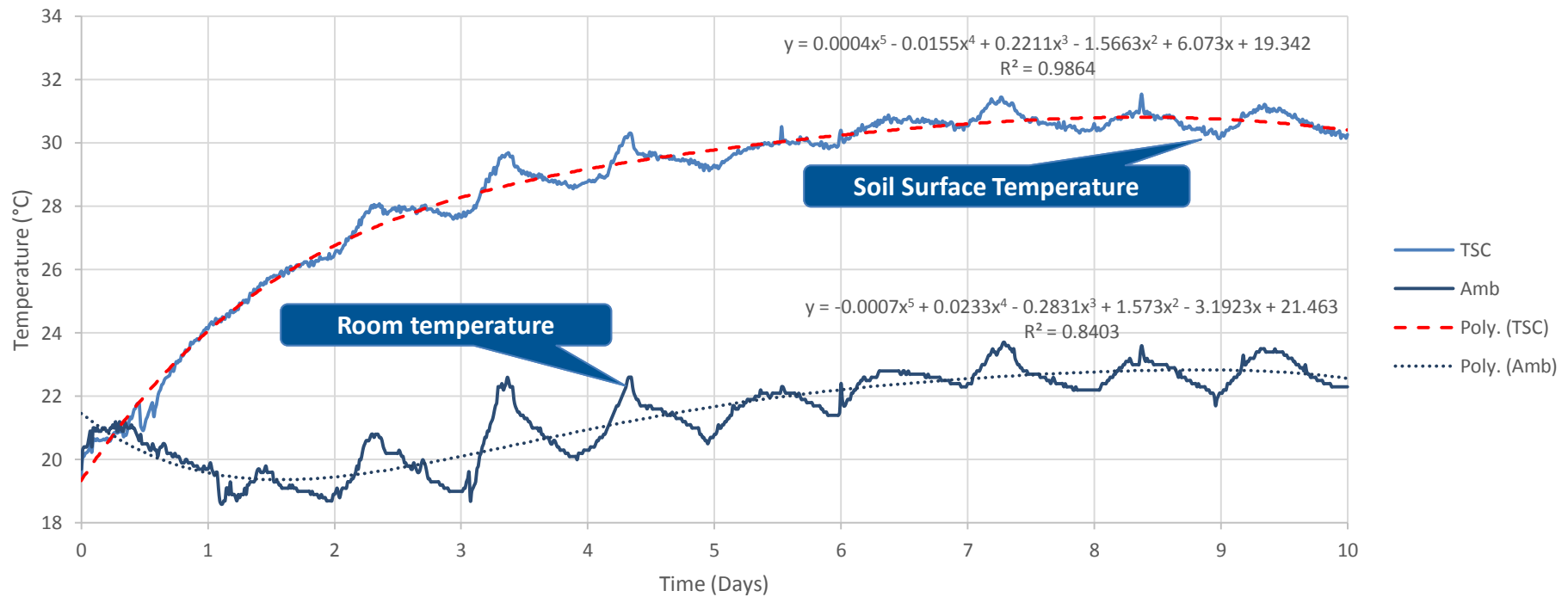
- Sharper soil temperature increase in first 48 hours.
- Gradual increase for the next 4 days.
- Very little increase between 6th and 10<sup>th</sup> days



IRT data at soil surface at various states of testing.



## Surface and Ambient Temperature Variations



IRT data trend over a ten day period.



# IRT Results Summary

- i. Infrared Thermography was able to detect 3" diameter CFRP pipe carrying hot water (95°C) at 14" soil depth.
- ii. Larger diameter pipes may be detectable at larger depths.



# Gas Leak Testing Apparatus

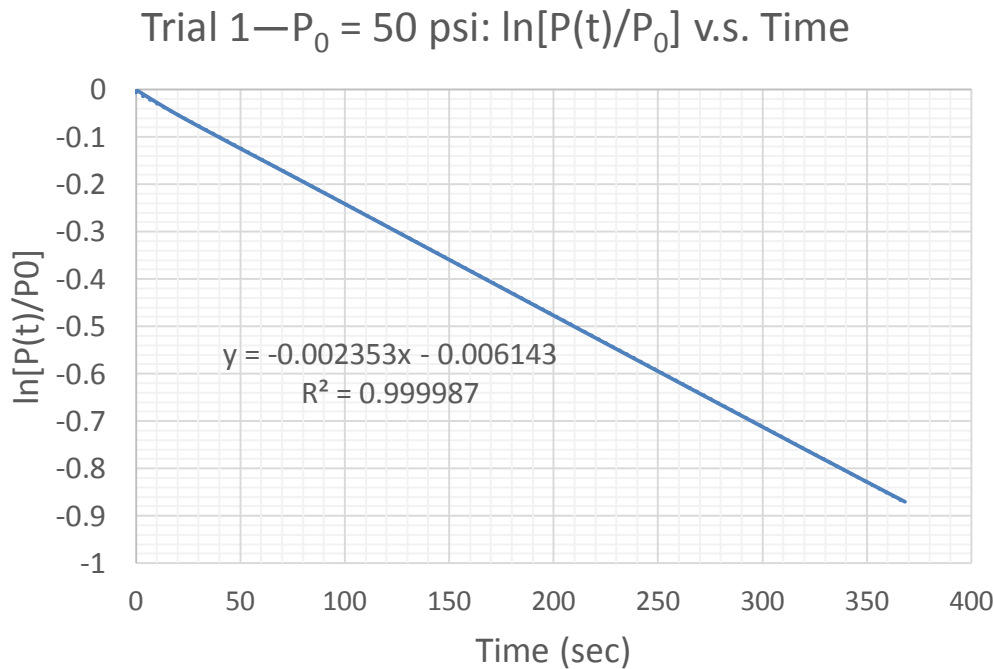
- Design an experimental testing apparatus capable of simulating the underground conditions faced by pipelines
- Testing with this apparatus will include:
  - Leak simulations
  - Leak detection – Tests will be performed using a *LM99 Cirrus* Mass Spectrometer
  - Model pressure change versus time with choked-flow analysis
  - Predict leak flow-rate vs. time and pressure



# Testing Apparatus



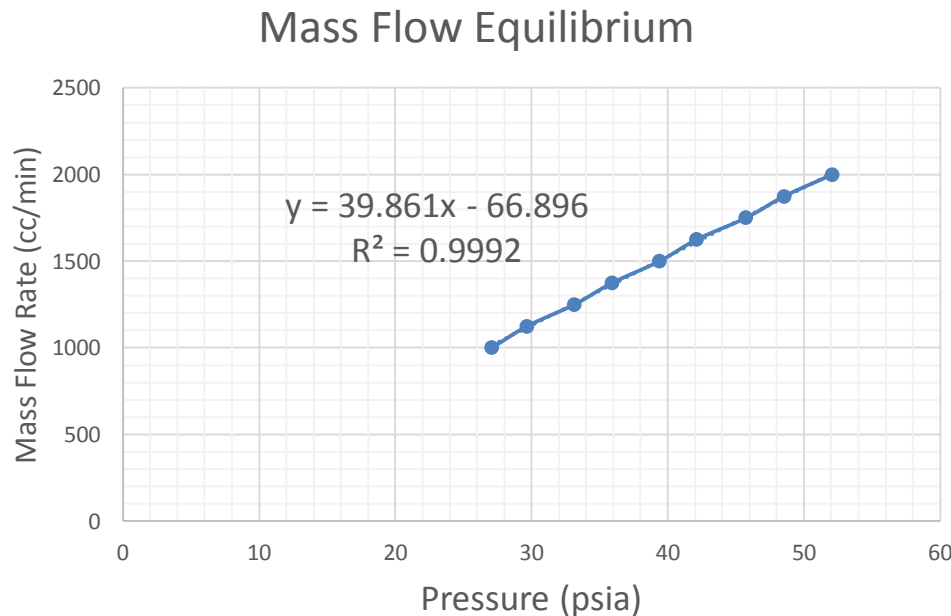
# Choked Flow Analysis



- $\ln \frac{P}{P_0}$  vs  $t$  analysis required in order to determine the validity of the choked-flow model
  - Theoretical Model:
$$\ln \frac{P}{P_{atm}} = -k't$$
  - Determined  $k'$  value
  - $k'$  = correlation of constants
  - Predict leak rate vs. pressure



# Mass Flow Equilibrium



- Mass flow trials were run above the choke flow pressure to verify the theoretical flow

- $\dot{m} =$

$$C_0 A P(t) \sqrt{\frac{\gamma g_c M}{R T_0} \left( \frac{2}{\gamma + 1} \right)^{\frac{\gamma + 1}{\gamma - 1}}}$$

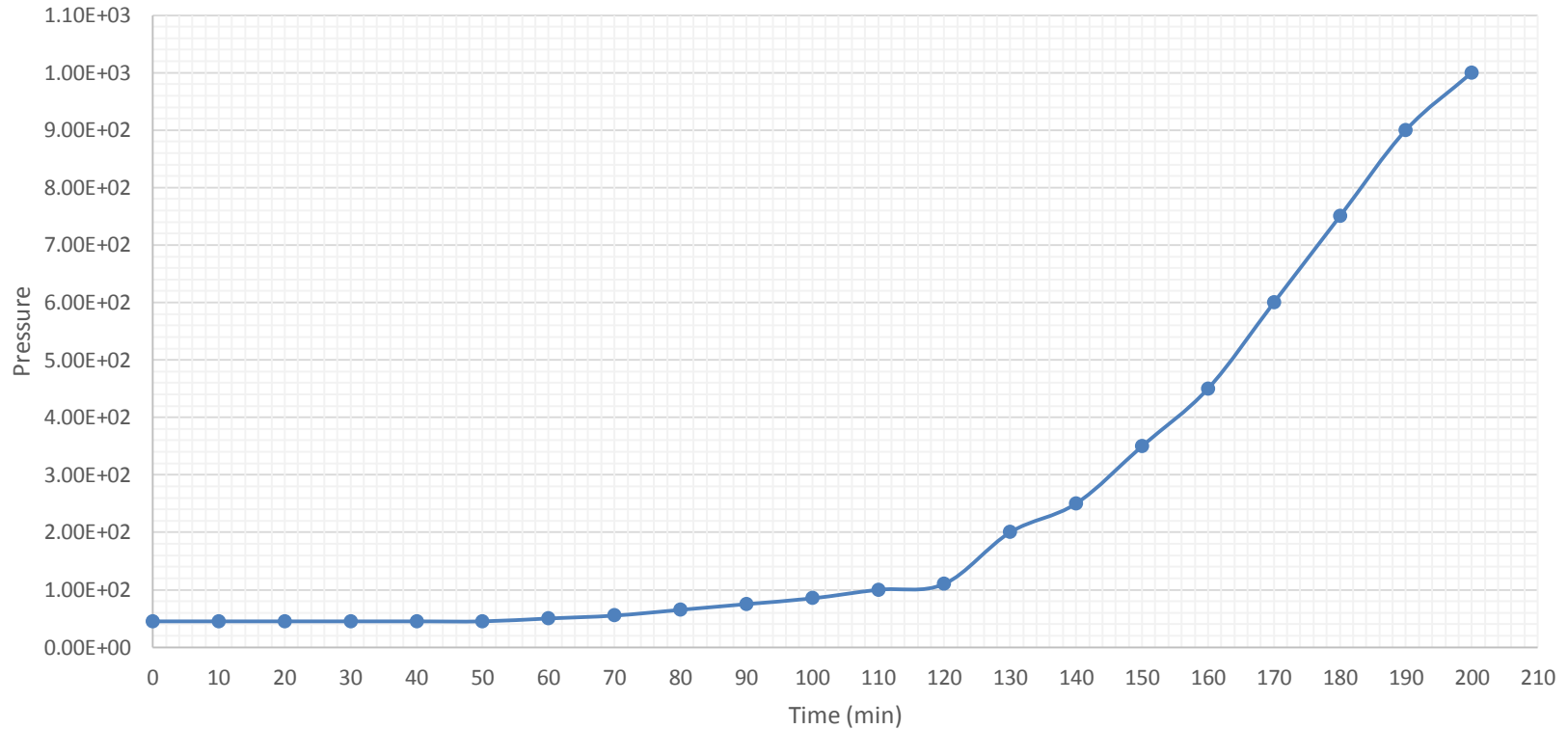
$$- \dot{m}(t) = K P(t)$$

- Will allow for better prediction of gas detection



# Gas Detection

Figure 4. Concentration of CO<sub>2</sub> (expressed as arbitrary pressure)



# On-Going Research - Next Phase

- One dimensional transient gas diffusion model
- Leak detection with different soil compactions
- Will lead to autonomous detection system



# Project Conclusions

- i. Current FRP pipe designs provide burst pressures up to 2300 psi, and additional work is being carried out to improve burst pressures (under another USDOT-PHMSA funded project).
- ii. GPR was able to detect pipes at 2' - 4' depth, and 200 MHz antenna was found to be more effective compared to 400 MHz antenna.
- iii. Use of CFRP fabric or Aluminum Foil on the surface made the non-metallic FRP pipes detectable using GPR.
- iv. The mass spectrometer provides a viable method for detecting a leak with the increase in gas concentration inside the soil.



# Project Reporting

- Final Report and any student poster papers are available from:

<https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=632>



# THANK YOU!

